Construction and First Operation of the 1GeV Electron Storage Ring for the Synchrotron Radiation Source at SORTEC

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ABSTRACT

The 1GeV electron, conventional storage ring with 8 FODO cells has been first-operated since September 1989. The current of 200mA has already been stored with lifetime of 4.0 hours. The vacuum is 4×10^{-11}Torr without the beam, and 2×10^{-9}Torr with the beam.

In the paper the lattice of the ring, the components, and the first operation are described.

INTRODUCTION

The SORTEC accelerator facility has a main function to generate the synchrotron light around the wave length of 1nm, which is required for the study of application fields including X-ray lithography.[1] The storage ring, what we call SOR(Synchrotron Orbital Radiation) ring is required to store 1GeV electron beam of current of 200mA, under the dipole field of 1.2T.

From the viewpoint that the function is established as fast as possible and the ring runs easily and stably, the magnets has been conventional typed, and the ring has been designed to be injected the beam to at the top energy of 1GeV from a synchrotron which is an injector.[2] Figure 1 shows the layout of the ring.

The design of the whole accelerator system started in December 1987, the manufacture around July 1988, and the setting and installation in October. The first operation started in July 1989, and the first beam was injected to the SOR ring on September 27. The ring has been operated for beam cleaning, and tuning up beam monitors and beam optics.

LATTICE DESIGN

The ring, made of 8 FODO cells, has a focusing structure of 4 superperiodicity, equipped with 8 conventional dipoles, 16 quadrupoles (QFs and QDs) and 8 sextupoles (SFs and SDs) and 8 straight sections.

The main aim of the ring is to provide the X-ray source previously described. In the case of such a ring of small circumference as the ring, an FODO lattice makes betatron function behavior smoother and C.O.D. smaller than a double achromatic lattice, which gives a longer life to the beam and does not make the emittance so low. Such a beam characteristic is necessary for realization of the aim. The expected C.O.D. without correction is 5.4mm horizontally(X) and 2.1mm vertically(Y). The useful aperture has been designed to be 66mm wide and 38mm high, whose values are about $2\times(2.5\times\text{C.O.D.}+10\times\sigma)$ for both directions, σ being half beam size. Touscheck lifetime of the beam of 200mA is estimated to be 40 hours, and the quantum lifetime 140 hours. Figure 2 shows betatron and dispersion functions. Table 1 shows main parameters of the ring.

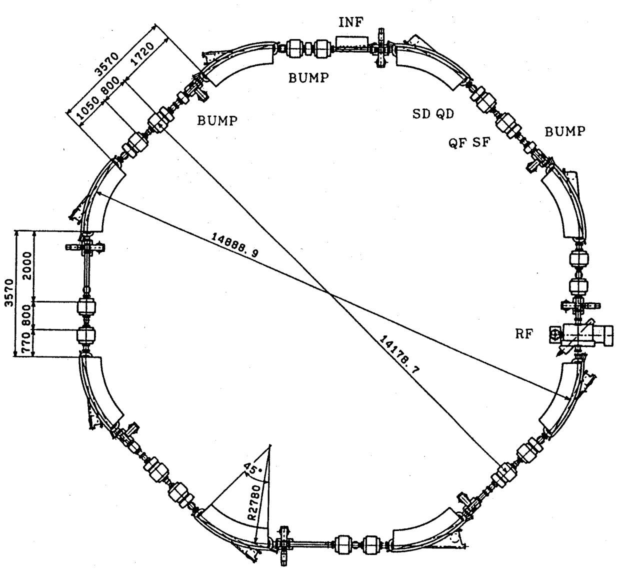

Fig. 1 Layout of the ring.

Table 1

Main parameters of the storage ring

Beam Energy(GeV)	1
Circumference(m)	45.73
Average Radius(m)	7.28
Dipole Field(T)	1.2
Focusing Structure	FODO
Betatron Tune νx	2.235
νy	2.215
RF Frequency(MHz)	118
RF Voltage Vc(kV)	90
Momentum Compaction Factor	0.17
Radiation Loss(keV/turn)	32
Natural Emittance(mm×mrad) ε_{xo}	0.5
Maximum Beam Size σ_x (mm)	2.0(at $\varepsilon_y/\varepsilon_{xo}$=0.1)
σ_y(mm)	0.7(at $\varepsilon_y/\varepsilon_{xo}$=0.4)
Touscheck Lifetime at 200mA(hour)	40

The beam from the injector is injected to the ring with a septum magnet as an inflector and three bump magnets. Figure 3 shows the motions of the injected and stored beams on the horizontal phase space at the exit of the septum magnet. The transport line from the injector to the ring was designed to be achromatic at the exit, as the beam size could become small in the septum magnet and therefore the septum got thin. The betatron function at the exit was determined in order that the injection efficiency could get high.

The thickness of the septum including a vacuum partition of the inflector chamber is 6mm, and the full size of the beam was estimated to be 6mm. The bump orbit was designed to be shifted at the velocity of 4 mm/turn.

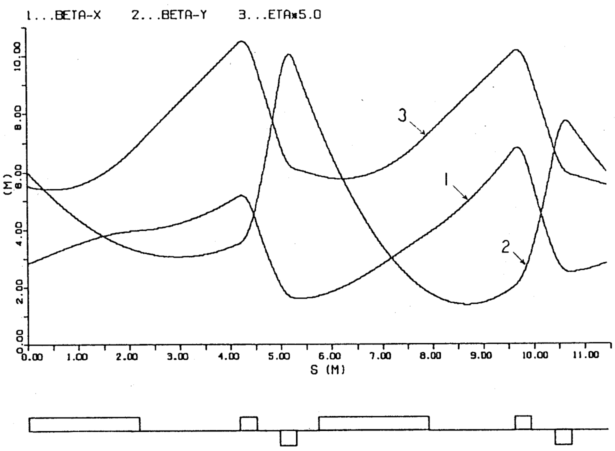

Fig. 2 Betatron and dispersion functions.

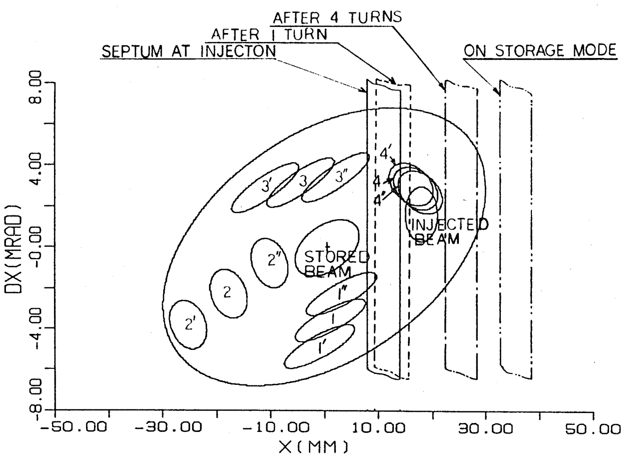

Fig. 3 Motions of injected and stored beams at the exit of the inflector.
1,2,3,4: beam($\Delta E/E$=0%) after 1,2,3 and 4 turns,
1',2',3',4': beam($\Delta E/E$=-0.2%) after 1,2,3 and 4 turns,
1",2",3",4": beam($\Delta E/E$=0.2%) after 1,2,3 and 4 turns.

DIPOLES

Magnets are conventional DC ones. Table 2 shows the main specifications.

TABLE 2

Specifications of the magnets

	Dipole	Quadrupole	Sextupole
Field	1.2T	10T/m	60T/m^2
Pole Length	2183mm	290mm	150mm
Effective Width on the median plane	84mm	66mm	66mm
Gap/Bore Radius	53mm	47mm	53mm
Uniformity	5×10^{-4} ($\Delta B/B$)	2×10^{-3} ($\Delta G/G$)	

The dipole is C-typed, as ports of synchrotron radiation and pump stations are easy to set on the chamber of the bending section. The vacuum chamber, the seethe heater and the thermal insulator have been installed in the pole gap of 53mm. The pole piece has been water-cooled, for the thickness of the insulator was reduced. The pole width and the shim profile were determined to be 200mm and 10mm wide $\times$0.45mm high respectively by the use of two-dimensional magnetostatic program JMAG2D, as shown in Fig. 4. The edges of pole pieces on the both ends were cut off with five steps, being approximated to the Rogowski's curve,[3] in order that the fringing field might have a structure less dependent on the radial direction. The manufacturing and assembling were done with the accuracy of $\pm25\mu$m.

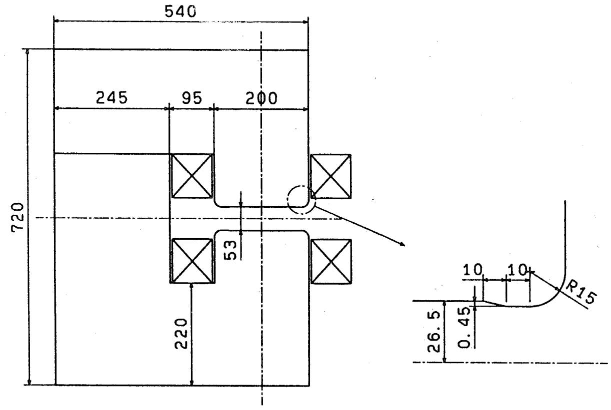

Fig. 4 Cross section of the dipole.

Field measurement was carried out with a power supply of stability better than $\pm1\times10^{-4}$and Hall-probe(F.W. Bell model 8860). Figure 5 shows the field structure in the radial direction. The good field region is known to extend over 84mm. The measured effective length was longer by 5.4mm than the designed one .

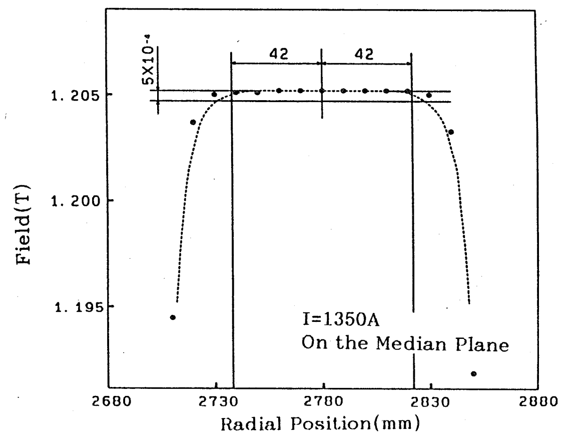

Fig. 5 Field of the dipole in the radial direction. The points mean the measured field, and the dotted line the calculated one. The pole center is at 2780mm.

ALIGNMENT

A level mark was made on the wall of the ring room at the height of the beam line from the floor, 120 cm, and an orienting mark made on the wall.

Dipoles were leveled within the slope of $\pm$0.01mrad, being measured by a leveler, and within the height of $\pm$0.1mm , being surveyed by using a theodolite. The theodolite was pointed to the level mark and the level target mounted on the lower pole surface of the magnets.

The surveying procedure for the horizontal alignment was as follows with the surveying instrument, the TOM CAT 2000 (Coordinate analyzing theodolite system). Every two neighboring dipoles were aligned at the designed positions, while targets on them were pointed the two theodolites to, after the fixed target at the center of the ring and the orienting mark were pointed the theodolites to, as shown in Fig. 6. After completion of the alignment, distances between the other neighboring magnets were measured for crosschecking the accuracy of the alignment. The alignment was done with the accuracy of ±0.08mm.

Quadrupoles and sextupoles on the straight section were leveled, while a theodolite was pointed to four targets mounted on the four corners of each lower half side of magnets and the level mark. The distances of the magnets from the dipoles were adjusted, being surveyed by an inside micrometer. At the same time, the magnets were centered on the beam line, being surveyed by another theodolite on the beam line which was pointed to the center targets on each lower half side of the magnets. The leveling and positioning were carried out within ±0.05mm.

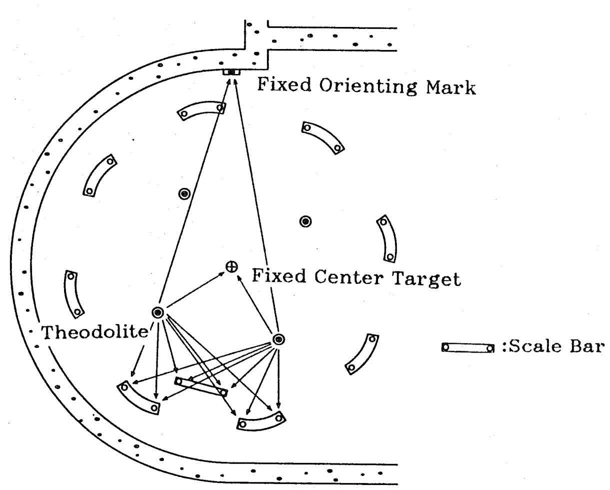

Fig. 6 Surveying procedure for the horizontal alignment of the dipoles. The instrument is rotated by 90° in turn for alignment of every two neighboring dipoles.

VACUUM SYSTEM

A vacuum of 10^{-9}Torr with the beam current of 200mA is required for the sufficiently long beam lifetime. For the purpose of achieving this pressure in a short term the vacuum system was designed to pump out photo-induced outgases effectively.

The vacuum chamber was made of SUS316L, 304L stainless steel and finished with electro-chemical polishing. After each component was assembled to a sector consisting of a straight section and a bending section, each sector was baked out at 250°C for 48 hours in advance. The vacuum of each sector was achieved below 3×10^{-10} Torr. The averaged vacuum less than 1×10^{-11} Torr without the beam in the ring could be obtained by means of baking out at 150°C for 48 hours at the SORTEC site.

Figure 7 shows a structure of the vacuum sector. The chamber of the bending section is considerably spread outside of the beam orbit, where copious amount of photo-induced gases can be pumped out collectively. The chamber of the straight section has an inner cross section of 110mm×38mm race track.

In consideration of beam instability, the inner wall of the chamber was designed as smooth as possible and has ion-clearing electrodes both in straight sections and bending ones.

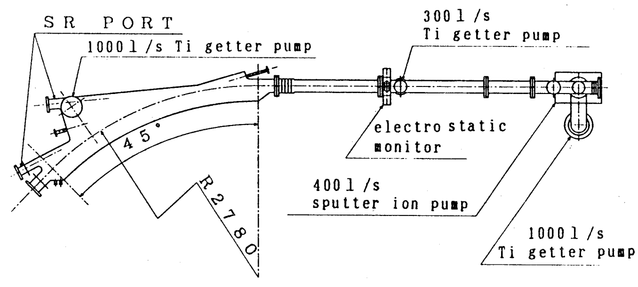

Fig. 7 A sector of vacuum chamber.

The straight section is equipped with 400*l*/s sputter ion pump and 1000*l*/s Ti getter pump at the end, and 300*l*/s Ti getter pump at the center. The bending section is equipped with 1000*l*/s Ti getter pump and a distributed ion pump. The RF cavity has an extra pumping system. The pumping speed of the doughnut is about 26000*l*/s in total.

RF SYSTEM

Table 3 shows parameters of the RF cavity. The cavity voltage Vc shown in Table 1 was determined to be 90kV by the demand that the lifetime of the beam is longer than 4 hours.

Table 3

Parameters of RF cavity

Inner Length of Cell (mm)	400
Inner Cavity Diameter (mm)	800
Diameter of Central Electrode (mm)	195
Gap Length (mm)	~22
Bore Diameter (mm)	110
Q calculated with SUPERFISH	24400
measured	20100
Shunt Impedance (MΩ)	
calculated with SUPERFISH	2.00
estimated from synchrotron frequency	1.35

The RF cavity is reentrant typed. The body has been made of copper-clad stainless, and the central electrodes of oxygen-free high conductive copper. Calculation with program code SUPERFISH indicated that the Q value was 24400, and the shunt impedance Rs 2.00MΩ. The cavity has 5 flanges, which make the both values decrease. On the assumption that Rs got half of the indicated 2.00MΩ, the 14kW power supply was prepared to compensate the synchrotron radiation loss induced by the beam of 200mA. The Q value was measured to be 20100 in the low power test. The Rs was estimated to be 1.35 MΩ from observed synchrotron frequency.

Figure 8 shows the control system. The signal source is generated by a synthesizer. The system contains three feedback loops:

1) stabilizer of the phase in the power supply
2) cavity voltage control loop
3) cavity phase control loop.

MONITORS

The screen monitor installed on every other straight section is used to monitor a single-turning beam. The material of the screen is 99.5% Al_2O_3 with chromium oxide. The monitor was very powerful even at the first time when the beam was injected to the ring.

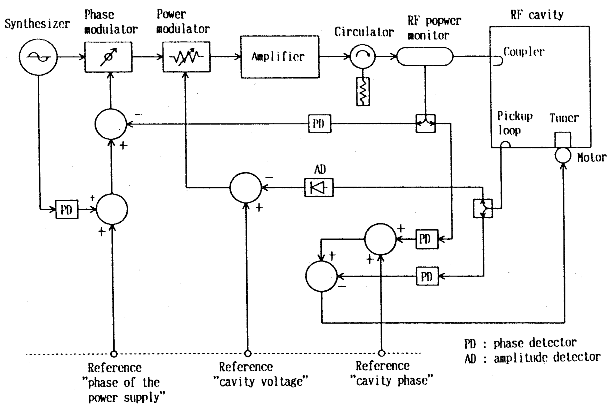

Fig. 8 RF control system.

The electrostatic monitor made of 4 disk electrodes is installed on each straight section. It is used as a position monitor when the signal from it is transmitted to a superheterodyne circuit to be digitized by an ADC. The monitor has a sensitivity to beam current of 0.1mA.

The monitor is used as a tune monitor also when the signal from it is directly analyzed by a spectrum analyzer. The beam is kicked with an RF kicker (deflection electrodes)[4].

The DC current transformer(Kudo KS-102) has a sensitivity to beam current of 10μA.

The SR port available for the beam diagnosis is on every bending section. A beam profile is displayed on the TV monitor.

FIRST OPERATION

The ring started first operation on September 27 in 1989. The excitation levels of magnets were adjusted in order that the beam might single-turn in the ring. On 28th, as soon as the RF system ran with power of 4kW, SR light was observed to blink coincidently with the injection. After excitation levels of bump magnets were only adjusted, the first storage of current 3.5mA was succeeded in with the lifetime of about 10 minutes.

Since then, the operation has been continued for the purposes of 1) tuning up the beam monitors, 2) tuning up beam optics, and 3) beam cleaning, on the condition that the vacuum is kept better than 10^{-8}Torr and that input RF power does not exceed the designed one. On October 23, after the RF cavity was detuned to avoid Robinson instability, the current of 200mA was achieved. On 31st, the lifetime of the current got 4.0 hours under the vacuum of 2×10^{-9} Torr and with the sextupoles excited for suppression of the transverse instability, as shown in Fig. 9.

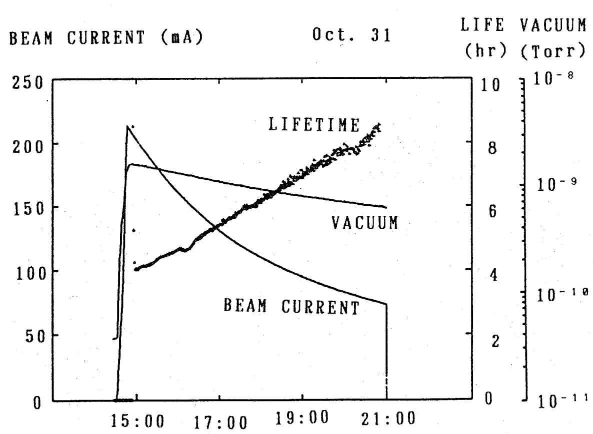

Fig. 9 Lifetime of the stored beam.

Figure 10 shows the increase of the current during the injection. A stored current per shot is about 3.5mA, when the current of accelerated beam is around 25mA in the injector. The shot cycle is 3.2 seconds, which is 4 times longer than the normal cycle, because of tuning up the beam optics. Figure 11 shows the brief history of the beam lifetime.

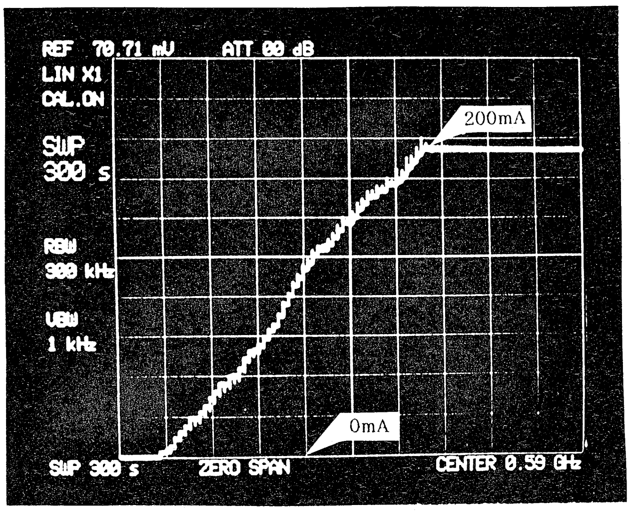

Fig. 10 Beam current during the injection.

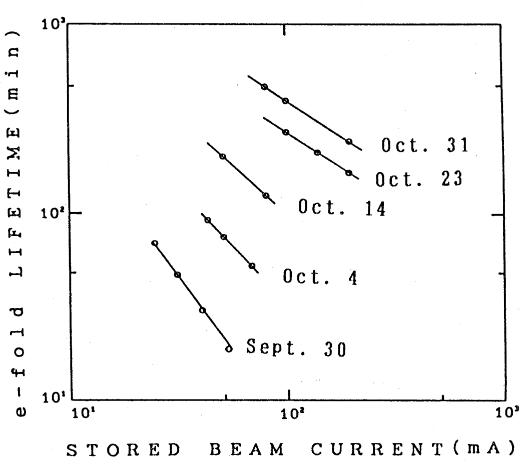

Fig. 11 History of the beam lifetime. The ion clearing has been carried out since Oct. 23.

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